REMARKS/ARGUMENTS

The Applicants hereby thank the Examiner for the observations in the outstanding Office Action. Independent Claims 1, 10, 15, and 16, have been previously amended to better encompass the full scope and breadth of the present invention, notwithstanding the Applicants' belief that the Claims would have been allowable as originally filed as well as herein amended.

The previously presented amendments are believed to be fully supported by the priority document, U.S. Provisional Patent Application Serial No. 60/520,752, entitled "Ring Interface for TV Programming Guide," filed on November 17, 2003, as well as the following documents having been incorporated by reference in the present application: U.S. Patent Application Serial No. 10/806,713, entitled "3-Dimensional Browsing and Selection Apparatus and Method," filed on March 23, 2004; U.S. Patent Application Serial No. 10/806,876, entitled "Candidate Data Selection and Display Apparatus and Method," filed on March 23, 2004; U.S. Patent Application Serial No. 10/806,832, entitled "Filter Criteria and Results Display Apparatus and Method," filed on March 23, 2004; U.S. Patent Application Serial No. 10/806,712, entitled "Automatic Content Display Apparatus and Method," filed on March 23, 2004; U.S. Patent Application Serial No. 10/806,646, entitled "Display Filter Criteria and Results Display Apparatus and Method," filed on March 23, 2004; and U.S. Patent Application Serial No. 10/806,767, entitled "Multi-Source Programming Guide Apparatus and Method," filed on March 23, 2004.

The Applicants respectfully assert that no claim has been narrowed within the meaning of *Festo Corp. v. Shoketsu Kinzoku Kogyo Kabushiki Co.* (Fed.Cir. November 29, 2000). Therefore, reconsideration of the present application in light of the foregoing amendment and these remarks is respectfully requested. However, should any remaining issues be outstanding, the Examiner is respectfully requested to telephone Mr. Thomas F. Lebens at (805) 781-2865 so that such issues may be resolved as expeditiously as possible.

I. Rejection of Claims 1-2, 8-12, 15, and 16 under 35 U.S.C. §112, first paragraph

Claims 1-2, 8-12, 15, and 16 stand rejected, under 35 U.S.C. §112, first paragraph, as assertedly failing to comply with the written description requirement. The Examiner states: "Nowhere in the drawings or the specification is reference made to 'cascading filters," and Applicant did not point Examiner to any place where Applicant may believe this amendment is supported." The Applicants respectfully traverse these grounds for rejection on this basis.

The Applicants have pointed out the supporting disclosure for "cascading filters" to the Examiner in the **January 26, 2009, Response to Final Office Action (p. 11, first paragraph, ll. 5-7)**. The Applicant reiterates that the supporting disclosure is found in the priority document, **U.S. Provisional Patent Application Serial No. 60/520,752 (cascading filters: p. 3, paragraph 4; smart filters: p. 8, paragraphs 5-8; p. 10, paragraph 5). Further, U.S. Patent Application Serial No. 10/806,832, entitled "Filter Criteria and Results Display Apparatus and Method," filed on March 23, 2004, discloses "two or more characterizing descriptor filters (paragraphs 22, 23, 29, and 33); U.S. Patent Application Serial No. 10/806,646, entitled "Display Filter Criteria and Results Display Apparatus and Method," filed on March 23, 2004, discloses the same (paragraphs 24-26, 31, 35, and 36); U.S. Patent Application Serial No. 10/806,712, entitled "Automatic Content Display Apparatus and Method," filed on March 23, 2004, discloses "characterizing descriptor filter criteria" (paragraph 34); U.S. Patent Application Serial No. 10/806,876, entitled "Candidate Data Selection and Display Apparatus and Method," filed on March 23, 2004, discloses "at least one characterizing descriptor filter" (paragraph 28); and U.S. Patent Application Serial No. 10/806,767, entitled "Multi-Source Programming Guide Apparatus and Method," filed on March 23, 2004, discloses the same (paragraph 30), wherein U.S. Patent Application Serial No. 10/806,713, entitled "3-Dimensional Browsing and Selection Apparatus and Method," filed on March 23, 2004, incorporates the disclosures of these foregoing documents by reference as well. The presently claimed "plurality of cascading filters" is synonymous with "the plurality of characterizing descriptor filters."**

Thus, the Applicants respectfully submit that Claims 1-2, 8-12, 15, and 16 are fully supported by the originally filed Specification. Therefore, the Applicants respectfully request that these grounds for rejection of on this basis are withdrawn and that Claims 1-2, 8-12, 15, and 16 are passed to allowance in due course.

II. Rejection of Claims 1-2, 8-13, 15, and 16 under 35 U.S.C. §103(a)

Claims 1-2, 8-13, 15, and 16 stand rejected, under 35 U.S.C. § 103(a), as being unpatentable over Ellis et al. (US 2004/0117831), in view of Robarts et al. (US 2005/0278741), and in further view of Hassell et al. (US 2004/0107439) and Westberg (US 2005/0102696). The Applicants respectfully traverse these grounds for rejection on this basis. Independent Claims 1, 10, 15, and 16 have been respectively previously amended to include language involving "cascading **filters**."

With respect to the primary cited reference, Ellis merely discloses "[a] system for providing interactive television program guide features and other features and information related to a specific user interest or programming category in niche hubs is provided. All of the television programming features provided by user television equipment that relate to a specific user interest or programming category may be accessed from the niche hub. For example, a movie lovers niche hub may provide programming features such as television program listings for movies, video-on-demand listings for movies, pay-per-view listings for movies, web site links related to movies, movie-related merchandise, movie news groups, movie chat groups, movie e-mail clubs, movie contests, movie trivia questions, movie actor interviews, movie reviews, movie channel package ordering, etc. ...." (Abstract).

With respect to the secondary cited reference, Robarts merely discloses "[a]n electronic program guide (EPG) organizes and presents programming information to the viewer and allows for creation of queries to facilitate both simple and complex searches of the programming information. According to one aspect, the EPG is configured to automatically identify programs that a viewer is likely to prefer. The EPG collects viewing preferences of a viewer and, based upon ... these viewing preferences, automatically develops queries for identifying programs that

the viewer is likely to want to watch ...." (Abstract).

With respect to the tertiary cited reference, Hassell merely discloses "[a]n electronic program guide that assists a user to navigate through a variety of digital and analog feeds made available by digital television technology is provided. Features such as allowing the user to purchase items, allowing the user to choose the content of the display screen, enabling more efficient use of black areas, among others are provided. Default settings based on prior user settings is provided to allow for an automatically customized environment. This automatic customization may entail, for example, the automatic resizing of windows based on the user's prior preferences. Also provided is a feature that allows for the automatic activation of a local or remote application through the user's set-top box based on the content currently being viewed." (Abstract).

With respect to the quaternary cited reference, Westberg merely discloses "[a]n interactive television program guide application is provided that queries a user regarding the user's interest in television programs and suggests television programs to the user based the user's responses. The interactive television program guide application identifies a television program that is potentially of interest to the user. The interactive television program guide application then queries the user regarding the user's interest using questions that are formulated based on attributes associated with the identified television program. Using the user's responses to the questions, the interactive television program guide application identifies and suggests one or more television programs to the user." (Abstract).

Regarding the cited art, the Examiner concedes that "[t]he combined teaching of Ellis and Robarts does not disclose providing a plurality of cascading filters for facilitating determination of a particular one of the discrete selectable audio/visual programs, the plurality of cascading filters being customizable for each at least one user, nor does it disclose wherein the plurality of discrete selectable audio/visual programs are embodied in a plurality of media, wherein the plurality of cascading filters simultaneously considers content across the plurality of media." The Examiner relies on Hassell for assertedly disclosing "that ***windows*** can be displayed in a *cascading fashion* (Figs 18A and 18B, paragraph [0118])" and "that the content in the *cascading*

windows may be retrieved from a plurality of different feeds that are interspersed among a plurality of analog carriers (Fig. 24, paragraph [0128])."

Indeed, Hassell discloses a plurality of **windows** that are displayed in a *cascading fashion* (Figs 18A and 18B; paragraphs [0038], [0039], and [0118]); however, the Applicants respectfully submit that *cascading* ***windows*** are not tantamount to *cascading* ***filters***, albeit the terminology may seem similar on first glance. *Cascading* ***filters*** are actually an entirely different animal. They are not merely the windows that appear on a display screen. Rather, they are the electronic components that are disposed in a specific type of circuit arrangement. The circuit arrangement is what is "cascaded." An example of such a filter is a cascaded series of second-order biquadratic sections for limiting the filter coefficient range, because the delay elements of the input of any section, other than the first section, are redundant in relation to the delay elements of the output of any preceding section (See Exhibit A).[1] Typically, cascading filters are generally repeating filters connected in a cascade configuration. Typical cascade systems are of a higher order, e.g., having a longer or finite impulse response (See Exhibit B).[2] Thus, the presently claimed *cascading* ***filters*** bear no relation whatsoever to Hassell's *cascading* ***windows***.

In contrast to the cited art, the present invention methods each involve the following salient features, *inter alia*: "providing a plurality of *cascading* ***filters*** for facilitating determination of a particular one of the discrete selectable audio/visual programs, the plurality of *cascading* ***filters*** being customizable for each at least one user[,]" "wherein the plurality of *cascading* ***filters*** simultaneously considers content across the plurality of media," and "automatically adding information corresponding to a particular one of the plurality of discrete selectable items of audio/visual content to the updatable list of preferred items of audio/visual content when the area of visual focus is on a characterizing descriptor as corresponds to the particular one of the plurality of discrete selectable items of audio/visual content for greater than a predetermined length of time[.]" Nowhere in the cited art can any teaching, suggestion, motivation, or other obviation be found for combining the following claimed features:

---

[1] http://www.answers.com/topic/digital-filter, p. 5, downloaded June 11, 2009.
[2] http://www.ee.columbia.edu/~dpwe/e4810/lectures/L06-filters.pdf, pp. 17-19, published October 14, 2008, downloaded June 11, 2009.

"providing a plurality of *cascading filters* for facilitating determination of a particular one of the discrete selectable audio/visual programs, the plurality of *cascading filters* being customizable for each at least one user[,]" "wherein the plurality of *cascading filters* simultaneously considers content across the plurality of media," and "automatically adding information corresponding to a particular one of the plurality of discrete selectable items of audio/visual content to the updatable list of preferred items of audio/visual content when the area of visual focus is on a characterizing descriptor as corresponds to the particular one of the plurality of discrete selectable items of audio/visual content for greater than a predetermined length of time[.]" [emphasis added]

As such, the Applicants respectfully submit that the cited art does not teach, suggest, motivate, or otherwise obviate the combination of elements and limitations, *inter alia*, as respectively recited in herein amended independent Claims 1, 10, 15 and 16, the salient features being emphasized as follows:

1. A method of using an interactive program guide, comprising the steps of:

providing access to characterizing descriptors as individually correspond to a plurality of discrete selectable audio/visual programs;

displaying an interactive program guide comprising at least one of the characterizing descriptors as corresponds to a particular one of the discrete selectable audio/visual programs;

providing a plurality of cascading filters for facilitating determination of a particular one of the discrete selectable audio/visual programs, the plurality of cascading filters being customizable for each at least one user;

detecting preliminary selection of a particular one of the discrete selectable audio/visual programs to provide a preliminarily selected audio/visual program;

when a user selects the preliminarily selected audio/visual program, automatically taking a first predetermined action with respect to the preliminarily selected audio/visual program;

when a user preliminarily selects a different one of the plurality of discrete selectable audio/visual program, automatically taking a second predetermined action with respect to the preliminarily selected audio/visual program, which second predetermined action is different than the first predetermined action;

when a user takes an action with respect to the preliminarily selected audio/visual program, which action does not comprise either selecting the preliminarily selected audio/visual program or preliminarily selecting a different audio/visual program, automatically taking a third predetermined action with respect to the preliminarily selected audio/visual program, which third predetermined action is different than the first and the second predetermined action; and

automatically adding information corresponding to a particular one of the plurality of discrete selectable items of audio/visual content to the updatable list of preferred items of audio/visual content when the area of visual focus is on a characterizing descriptor as corresponds to the particular one of the plurality of discrete selectable items of audio/visual content for greater than a predetermined length of time,

wherein the plurality of discrete selectable audio/visual programs are embodied in a plurality of media,

wherein the plurality of cascading filters simultaneously considers content across the plurality of media,

wherein the step of automatically taking a first predetermined action comprises adding information regarding the preliminarily selected audio/visual program to a list of preferred items,

wherein the step of automatically taking a second predetermined action comprises moving an area of visual focus away from the preliminarily selected audio/visual program, and

wherein the step of automatically taking a third predetermined action comprises displaying the list of preferred items. [emphasis added]

10. A method of providing an interactive programming guide, comprising the steps of:

providing access to characterizing descriptors as individually correspond to a plurality of discrete selectable items of audio/visual content;

providing an updatable list of preferred items of audio/visual content;

displaying an interactive programming guide comprising at least one of the characterizing descriptors;

providing a plurality of cascading filters for facilitating determination of a particular one of the discrete selectable audio/visual programs, the plurality of cascading filters being customizable for each at least one user;

providing an area of visual focus on a particular displayed one of the characterizing descriptors;

in response to a first signal, adding information regarding the discrete selectable item of audio/visual content as corresponds to the particular displayed one of the characterizing descriptors as is presently in the area of visual focus to the updatable list of preferred items of audio/visual content;

in response to a second signal that is different from the first signal, moving the area of visual focus to a different one of the characterizing descriptors;

in response to a third signal that is different from both the first signal and the second signal, displaying the updatable list of preferred items of audio/visual content; and

automatically adding information corresponding to a particular one of the plurality of discrete selectable items of audio/visual content to the updatable list of preferred items of audio/visual content when the area of visual focus is on a characterizing descriptor as corresponds to the particular one of the plurality of discrete selectable items of audio/visual content for greater than a predetermined length of time,

wherein the plurality of discrete selectable items of audio/visual content are embodied in a plurality of media, and

wherein the plurality of cascading filters simultaneously considers content across the plurality of media. [emphasis added]

15. A method of using an interactive program guide, comprising the steps of:

providing access to characterizing descriptors as individually correspond to a plurality of discrete selectable audio/visual programs;

displaying an interactive program guide comprising at least one of the characterizing descriptors as corresponds to a particular one of the discrete selectable audio/visual programs;

providing a plurality of cascading filters for facilitating determination of a particular one of the discrete selectable audio/visual programs, the plurality of cascading filters being customizable for each at least one user;

detecting preliminary selection of a particular one of the discrete selectable audio/visual programs to provide a preliminarily selected audio/visual program;

determining when the user selects the preliminarily selected audio/visual program by detecting when the user asserts a selection action at a time when a characterizing descriptor as corresponds to the preliminarily selected audio/visual program occupies, at least in part, a same portion of a display as a predetermined area of visual focus;

when a user selects the preliminarily selected audio/visual program, automatically taking a first predetermined action with respect to the preliminarily selected audio/visual program;

when a user preliminarily selects a different one of the plurality of discrete selectable audio/visual program, automatically taking a second predetermined action with respect to the preliminarily selected audio/visual program, which second predetermined action is different than

the first predetermined action;

when a user takes an action with respect to the preliminarily selected audio/visual program, the action not comprising either selecting the preliminarily selected audio/visual program or preliminarily selecting a different audio/visual program, automatically taking a third predetermined action with respect to the preliminarily selected audio/visual program, which third predetermined action is different than the first and the second predetermined action; and

automatically adding information corresponding to a particular one of the plurality of discrete selectable items of audio/visual content to the updatable list of preferred items of audio/visual content when the area of visual focus is on a characterizing descriptor as corresponds to the particular one of the plurality of discrete selectable items of audio/visual content for greater than a predetermined length of time,

wherein the characterizing descriptors as individually correspond to a plurality of discrete selectable audio/visual programs comprise at least one element selected from a group consisting essentially of a programming network identifier, a broadcast starting time, a description of audio/visual content as corresponds to the audio/visual program, and an audio/visual program media source,

wherein the plurality of discrete selectable audio/visual programs are embodied in a plurality of media,

wherein the plurality of cascading filters simultaneously considers content across the plurality of media,

wherein the step of automatically taking a first predetermined action comprises adding information regarding the preliminarily selected audio/visual program to a list of preferred items,

wherein the step of automatically taking a second predetermined action comprises moving an area of visual focus away from the preliminarily selected audio/visual program,

wherein the step of automatically taking a third predetermined action comprises displaying the list of preferred items, and

wherein the step of detecting preliminary selection of a particular one of the discrete selectable audio/visual programs further comprises detecting at least a predetermined relationship between a present position of one of the characterizing descriptors as corresponds to the particular one of the discrete selectable audio/visual programs and an area of visual focus. [emphasis added]

16. A method of providing an interactive programming guide, comprising:

providing access to characterizing descriptors as individually correspond to a plurality of discrete selectable items of audio/visual content;

providing an updatable list of preferred items of audio/visual content;

displaying an interactive programming guide comprising at least one of the characterizing descriptors;

providing a plurality of cascading filters for facilitating determination of a particular one of the discrete selectable audio/visual programs, the plurality of cascading filters being customizable for each at least one user;

providing an area of visual focus on a particular displayed one of the characterizing descriptors;

in response to a first signal, adding information regarding the discrete selectable item of audio/visual content as corresponds to the particular displayed one of the characterizing descriptors as is presently in the area of visual focus to the updatable list of preferred items of audio/visual content;

in response to a second signal that is different from the first signal, moving the area of visual focus to a different one of the characterizing descriptors;

in response to a third signal that is different from both the first signal and the second signal, displaying the updatable list of preferred items of audio/visual content;

receiving at least one of the first signal, the second signal, and the third signal from a remote control device; and

automatically adding information corresponding to a particular one of the plurality of discrete selectable items of audio/visual content to the updatable list of preferred items of audio/visual content when the area of visual focus is on a characterizing descriptor as

> **corresponds to the particular one of the plurality of discrete selectable items of audio/visual content for greater than a predetermined length of time,**
>
> wherein the response to the third signal further comprises not displaying characterizing descriptors as correspond to items of audio/visual content that are not on the list of preferred items of audio/visual content,
>
> **wherein the plurality of discrete selectable items of audio/visual content are embodied in a plurality of media, and**
>
> **wherein the plurality of cascading filters simultaneously considers content across the plurality of media.** [emphasis added]

Consequently, Claims 2 and 8-12 now subsume the limitations of their respective base claims by dependency thereto.

Thus, the Applicants respectfully submit that Claims 1-2, 8-12, 15, and 16 have not been taught, suggested, motivated, or otherwise obviated by the cited art. Therefore, the Applicants respectfully request that the grounds for rejection on this basis are withdrawn and that Claims 1-2, 8-12, 15, and 16 are passed to allowance in due course.

CONCLUSION

Accordingly, independent Claims 1, 10, 15, and 16 have been previously amended to better encompass the full scope and breadth of the present invention, notwithstanding the Applicants' belief that the Claims would have been allowable as originally filed as well as herein amended. The Applicants respectfully reassert that no claim has been narrowed within the meaning of *Festo Corp. v. Shoketsu Kinzoku Kogyo Kabushiki Co.* (Fed.Cir. November 29, 2000). Therefore, reconsideration of the present application in light of the foregoing amendment and these remarks is respectfully requested. ***The Examiner is further cordially invited to telephone Mr. Thomas F. Lebens for any reason which would advance allowance of the pending claims.*** In the event that any additional fees become due or payable, the Examiner is authorized to charge USPTO Deposit Account No. 06-1135 accordingly.

Respectfully submitted,

Dated: June 26, 2009

May Lin DeHaan
May Lin DeHaan
Reg. No. 42,472
Attorney for Applicant

Address all correspondence to:
Thomas F. Lebens
FITCH, EVEN, TABIN & FLANNERY, LLP
Suite 1600, 120 South LaSalle Street
Chicago, Illinois 60603

Direct telephone inquiries to:
Thomas F. Lebens
(805) 781-2865

\\Server01\Data\TRANS\IP\81233\81233.7114 RTOA Amdmt D (rev 20090619).doc

EXHIBIT A

Answers.com®

Digital filter

Sci-Tech Dictionary: digital filter
('dij·əd·əl 'fil·tər)

(*electronics*) An electrical filter that responds to an input which has been quantified, usually as pulses.

Sci-Tech Encyclopedia: Digital filter

Any digital computing means that accepts as its input a set of one or more digital signals from which it generates as its output a second set of digital signals. While being strictly correct, this definition is too broad to be of any practical use, but it does demonstrate the possible extent of application of digital-filter concepts and terminology.

Capabilities

Digital filters can be used in any signal-manipulating application where analog or continuous filters can be used. Because of their utterly predictable performance, they can be used in exacting applications where analog filters fail because of time- or other parameter-dependent coefficient drift in continuous systems. Because of the ease and precision of setting the filter coefficients, adaptive and learning digital filters are comparatively simple and particularly effective to implement. As digital technology becomes more ubiquitous, digital filters are increasingly acknowledged as the most versatile and cost-effective solutions to filtering problems.

The number of functions that can be performed by a digital filter far exceeds that which can be performed by an analog, or continuous, filter. By controlling the accuracy of the calculations within the filter (that is, the arithmetic word length), it is possible to produce filters whose performance comes arbitrarily close to the performance expected of the perfect models. For example, theoretical designs that require perfect cancellation can be implemented with great fidelity by digital filters.

Linear difference equation

The digital filter accepts as its input signals numerical values called input samples and produces as its output signal numerical values called output samples. Each output sample at any particular sampling instant is a weighted sum of present and past input samples, and past output samples. If the sequence of input samples is x_n, x_{n+1}, x_{n+2}, ..., then the corresponding sequence of output samples would be y_n, y_{n+1}, y_{n+2}, ... *See also* Difference equation.

From this simple time-domain expression, a considerable number of definitions can be constructed. If the filter coefficients (the a's and the *b*'s) are independent of the *x*'s and *y*'s, this digital filter is a linear filter. If the a's and *b*'s are fixed, this is a linear time-invariant (LTI) filter. The order of the filter is given by the largest of the subscripts among the *a*'s and *b*'s, that is, the larger of *M* and *N*. If the *b*'s are all zero (that is, if the output is the weighted sum of present and past input samples only), the digital filter is referred to as a nonrecursive (having no feedback) or finite impulse response (FIR) filter because the response of the filter to an impulse (actually a unit pulse) input is simply the sequence of the "*a*" coefficients. If any value of *b* is nonzero, the filter is recursive (having feedback) and is generally an infinite impulse response (IIR) filter.

If the digital filter under consideration is not a linear, time-invariant filter, the transfer function cannot be used.

Transfer functions

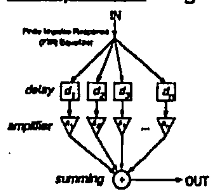
Although the time-domain difference equation is a useful description of a filter, as in the continuous-domain filter case, a powerful alternative form is the transfer function. The information content of the transfer function is the same as that of the difference equation as long as a linear,

time-invariant system is under consideration. A difference equation is converted to transfer-function form by use of the *z* transform. The *z* transform is simply the Laplace transform adapted for sampled systems with some shorthand notation introduced. *See also* Laplace transform; Z transform.

Adaptive filters

So far only LTI filters have been discussed. An important class of variable-parameter filter change their coefficients to minimize an error criterion. These filters are called adaptive because they adapt their parameters in response to changes in the operating environment. An example is an FIR digital filter whose coefficients are continually adjusted so that the output will track a reference signal with minimum error. The performance criterion will be the minimization of some function of the error. *See also* Electric filter.

Wikipedia: Digital filter



An FIR filter

In electronics, computer science and mathematics, a **digital filter** is a system that performs mathematical operations on a sampled, discrete-time signal to reduce or enhance certain aspects of that signal. This is in contrast to the other major type of electronic filter, the analog filter, which is an electronic circuit operating on continuous-time analog signals. An analog signal may be processed by a digital filter by first being digitized and represented as a sequence of numbers, then manipulated mathematically, and then reconstructed as a new analog signal (see digital signal processing). In an analog filter, the input signal is "directly" manipulated by the circuit.

A digital filter system usually consists of an analog-to-digital converter (to sample the input signal), a microprocessor (often a specialized digital signal processor), and a digital-to-analog converter. Software running on the microprocessor can implement the digital filter by performing the necessary mathematical operations on the numbers received from the ADC. In some high performance applications, an FPGA or ASIC is used instead of a general purpose microprocessor.

Digital filters may be more expensive than an equivalent analog filter due to their increased complexity, but they make practical many designs that are impractical or impossible as analog filters. Since digital filters use a sampling process and discrete-time processing, they experience latency (the difference in time between the input and the response), which is almost irrelevant in analog filters.

Digital filters are commonplace and an essential element of everyday electronics such as radios, cellphones, and stereo receivers.

Contents

[hide]

Characterization of digital filters

A digital filter is characterized by its transfer function, or equivalently, its difference equation. Mathematical analysis of the transfer function can describe how it will respond to any input. As such, designing a filter consists of developing specifications appropriate to the problem (for example, a second-order lowpass filter with a specific cut-off frequency), and then producing a transfer function which meets the specifications.

The transfer function for a linear, time-invariant, digital filter can be expressed as a transfer function in the Z-domain; if it is causal, then it has the form:

$$H(z) = \frac{B(z)}{A(z)} = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2} + \cdots + b_N z^{-N}}{1 + a_1 z^{-1} + a_2 z^{-2} + \cdots + a_M z^{-M}}$$

where the order of the filter is the greater of *N* or *M*. See Z-transform's LCCD equation for further discussion of this transfer function.

This form is for a recursive filter, which typically leads to infinite impulse response behaviour, but if the denominator is unity, then this is the form for a finite impulse response filter.

Analysis techniques

A variety of mathematical techniques may be employed to analyze the behaviour of a given digital filter. Many of these analysis techniques may also be employed in designs, and often form the basis of a filter specification.

Typically, one analyzes filters by calculating how the filter will respond to a simple input. One can then extend this information to visualize the filter's response to more complex signals.

Impulse response

The impulse response, often denoted $H(z)$ or $h(n)$ is a measurement of how a filter will respond to the Kronecker delta function. For example, given a difference equation, one would set $x(0) = 1$ and $x(n) = 0$ for $n > 0$ and evaluate. In the case of linear time-invariant FIR filters, the impulse response is exactly equal to the sequence of filter coefficients $h(n) = b_n$. In general, the impulse response is a characterization of the filter's behaviour.

A plot of the impulse response will help to reveal how a filter will respond to a sudden, momentary disturbance.

Difference equation

In discrete-time systems, the digital filter is often implemented by converting the transfer function to a linear constant-coefficient difference equation (LCCD) via the Z-transform. The discrete frequency-domain transfer function is written as the ratio of two polynomials. For example:

$$H(z) = \frac{(z+1)^2}{(z-\frac{1}{2})(z+\frac{3}{4})}$$

This is expanded:

$$H(z) = \frac{z^2 + 2z + 1}{z^2 + \frac{1}{4}z - \frac{3}{8}}$$

and divided by the highest order of z:

$$H(z) = \frac{1 + 2z^{-1} + z^{-2}}{1 + \frac{1}{4}z^{-1} - \frac{3}{8}z^{-2}} = \frac{Y(z)}{X(z)}$$

The coefficients of the denominator, a_k, are the 'feed-backward' coefficients and the coefficients of the numerator are the 'feed-forward' coefficients, b_k. The resultant linear difference equation is:

$$y[n] = -\sum_{k=1}^{N} a_k y[n-k] + \sum_{k=0}^{M} b_k x[n-k]$$

or, for the example:

$$y[n] = -\frac{1}{4}y[n-1] + \frac{3}{8}y[n-2] + x[n] + 2x[n-1] + x[n-2]$$

This equation shows how to compute the next output sample, $y[n]$, in terms of the past outputs, $y[n-p]$, the present input, $x[n]$, and the past inputs, $x[n-p]$. Applying the filter to an input in this form is equivalent to a Direct Form I or II realization, depending on the exact order of evaluation.

Filter design

Main article: Filter design

The design of digital filters is a deceptively complex topic.[1] Although filters are easily understood and calculated, the practical challenges of their design and implementation are significant and are the subject of much advanced research.

There are two categories of digital filter: the recursive filter and the nonrecursive filter. These are often referred to as infinite impulse response (IIR) filters and finite impulse response (FIR) filters, respectively[2].

Filter realization

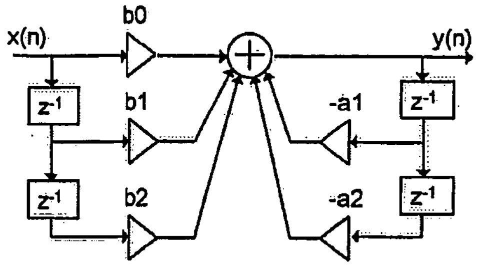
After a filter is designed, it must be *realized* by developing a signal flow diagram that describes the filter in terms of operations on sample sequences.

A given transfer function may be realized in many ways. Consider how a simple expression such as $ax + bx + c$ could be evaluated – one could also compute the equivalent $x(a + b) + c$. In the same way, all realizations may be seen as "factorizations" of the same transfer function, but different realizations will have different numerical properties. Specifically, some realizations are more efficient in terms of the number of operations or storage elements required for their implementation, and others provide advantages such as improved numerical stability and reduced round-off error. Some structures are more optimal for fixed-point arithmetic and others may be more optimal for floating-point arithmetic.

Direct Form I

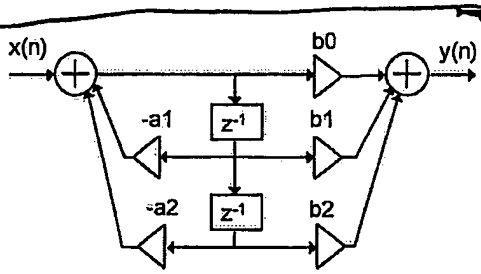
A straightforward approach for IIR filter realization is Direct Form I, where the difference equation is evaluated directly. This form is practical for small filters, but may be inefficient and impractical (numerically unstable) for complex designs[3]. In general, this form requires 2N delay elements (for both input and output signals) for a filter of order N.

is evaluated directly. This form is practical for small filters, but may be inefficient and impractical (numerically unstable) for complex designs[3]. In general, this form requires 2N delay elements (for both input and output signals) for a filter of order N.



Direct Form II

The alternate Direct Form II only needs N delay units, where N is the order of the filter – potentially half as much as Direct Form I. The disadvantage is that Direct Form II increases the possibility of arithmetic overflow for filters of high Q or resonance.[4] It has been shown that as Q increases, the round-off noise of both direct form topologies increases without bounds.[5] This is because, conceptually, the signal is first passed through an all-pole filter (which normally boosts gain at the resonant frequencies) before the result of that is saturated, then passed through an all-zero filter (which often attenuates much of what the all-pole half amplifies).



Cascaded second-order sections

A common strategy is to realize a higher-order (greater than 2) digital filter as a cascaded series of second-order "biquadratric" (or "biquad") sections[6] (see digital biquad filter). Advantages of this strategy is that the coefficient range is limited. Cascading direct form II sections result in N delay elements for filter order of N. Cascading direct form I sections result in N+2 delay elements since the delay elements of the input of any section (except the first section) are a redundant with the delay elements of the output of the preceding section.

Other Forms

This section requires expansion.

Other forms include:

- Series/cascade[7]
- Parallel[7]
- Ladder form[7]
- Lattice form[7]
- Coupled normal form
- Multifeedback
- Analog-inspired forms such as Sallen-key and state variable filters
- Systolic arrays

Comparison of analog and digital filters

component count, the effect of variable component errors is greatly magnified. In digital filters, the coefficient values are stored in computer memory, making them far more stable and predictable.[8]

Because the coefficients of digital filters are definite, they can be used to achieve much more complex and selective designs – specifically with digital filters, one can achieve a lower passband ripple, faster transition, and higher stopband attenuation than is practical with analog filters. Even if the design could be achieved using analog filters, the engineering cost of designing an equivalent digital filter would likely be much lower. Furthermore, one can readily modify the coefficients of a digital filter to make an adaptive filter or a user-controllable parametric filter. While these techniques are possible in an analog filter, they are again considerably more difficult.

Digital filters can be used in the design of finite impulse response filters. Analog filters do not have the same capability, because finite impulse response filters require delay elements.

Digital filters rely less on analog circuitry, potentially allowing for a better signal-to-noise ratio. A digital filter will introduce noise to a signal during analog low pass filtering, analog to digital conversion, digital to analog conversion and may introduce digital noise due to quantization. With analog filters, every component is a source of thermal noise (such as Johnson noise), so as the filter complexity grows, so does the noise.

However, digital filters do introduce a higher fundamental latency to the system. In an analog filter, latency is often negligible; strictly speaking it is the time for an electrical signal to propagate through the filter circuit. In digital filters, latency is a function of the number of delay elements in the system.

Digital filters also tend to be more limited in bandwidth than analog filters. High bandwidth digital filters require expensive ADC/DACs and fast computer hardware for processing.

In very simple cases, it is more cost effective to use an analog filter. Introducing a digital filter requires considerable overhead circuitry, as previously discussed, including two low pass analog filters.

Types of digital filters

Many digital filters are based on the Fast Fourier transform, a mathematical algorithm that quickly extracts the frequency spectrum of a signal, allowing the spectrum to be manipulated (such as to create band-pass filters) before converting the modified spectrum back into a time-series signal.

Another form of a digital filter is that of a state-space model. A well used state-space filter is the Kalman filter published by Rudolf Kalman in 1960.

References

General

- A. Antoniou, *Digital Filters: Analysis, Design, and Applications*, New York, NY: McGraw-Hill, 1993.
- J. O. Smith III, Introduction to Digital Filters with Audio Applications, Center for Computer Research in Music and Acoustics (CCRMA), Stanford University, September 2007 Edition.
- S.K. Mitra, *Digital Signal Processing: A Computer-Based Approach*, New York, NY: McGraw-Hill, 1998.
- A.V. Oppenheim and R.W. Schafer, *Discrete-Time Signal Processing*, Upper Saddle River, NJ: Prentice-Hall, 1999.
- J.F. Kaiser, *Nonrecursive Digital Filter Design Using the Io-sinh Window Function*, Proc. 1974 IEEE Int. Symp. Circuit Theory, pp. 20-23, 1974.
- S.W.A. Bergen and A. Antoniou, *Design of Nonrecursive Digital Filters Using the Ultraspherical Window Function*, EURASIP Journal on Applied Signal Processing, vol. 2005, no. 12, pp. 1910-1922, 2005.
- T.W. Parks and J.H. McClellan, Chebyshev Approximation for Nonrecursive Digital Filters with

Linear Phase, IEEE Trans. Circuit Theory, vol. CT-19, pp. 189-194, Mar. 1972.
- L. R. Rabiner, J.H. McClellan, and T.W. Parks, FIR Digital Filter Design Techniques Using Weighted Chebyshev Approximation, Proc. IEEE, vol. 63, pp. 595-610, Apr. 1975.
- A.G. Deczky, Synthesis of Recursive Digital Filters Using the Minimum p-Error Criterion, IEEE Trans. Audio Electroacoust., vol. AU-20, pp. 257-263, Oct. 1972.

Cited

1. ^ M. E. Valdez, Digital Filters, 2001.
2. ^ A. Antoniou, chapter 1
3. ^ J. O. Smith III, Direct Form I
4. ^ J. O. Smith III, Direct Form II
5. ^ L. B. Jackson, "On the Interaction of Roundoff Noise and Dynamic Range in Digital Filters," *Bell Sys. Tech. J.*, vol. 49 (1970 Feb.), reprinted in *Digital Signal Process*, L. R. Rabiner and C. M. Rader, Eds. (IEEE Press, New York, 1972).
6. ^ J. O. Smith III, Series Second Order Sections
7. ^ a b c d A. Antoniou
8. ^ http://www.dspguide.com/ch21/1.htm

See also

- Analog filter
- Bessel filter
- Butterworth filter
- Elliptical filter (Cauer filter)
- Linkwitz-Riley filter
- Chebyshev filter
- Ladder filter
- Digital signal processing
- Sample (signal)
- Electronic filter
- Filter design
- Biquad filter
- High-pass filter, Low-pass filter
- Infinite impulse response, Finite impulse response
- Z-transform
- Bilinear transform

External links

- WinFilter – Free filter design software
- Filtplot – Free customizable digital filter design software built with python and boost (WinXP/Ubuntu 6.10/RHEL-4). Also with interactive web interface.
- DISPRO – Free filter design software
- Java demonstration of digital filters
- IIR Explorer educational software
- FIWIZ – Filter design wizard (FIR, IIR)
- Introduction to Filtering
- Introduction to Digital Filters

Learn More

- nonrecursive filter (electronics)
- recursive filter (electronics)
- Active sound control (acoustics)

- Why is a recently purchased Sharp Aquos showing analog as opposed to **digital** on the screen display when **digital** TV service is subscribed and the **digital** terminal is hooked up to the cableTV? *Read answer...*
- How do you attach a UV **filter** to a **Digital** D40 SLR camera? *Read answer...*
- Will your **digital** television thats receiving an analog signal from comcast be a clear picture **digital** signal when you go **digital** in 2009? *Read answer...*

Help us answer these

- Which disc type is best to copy **digital** picture or **digital** videos to after downloading pictures from the **digital** camera if you want to send a disc to friends?
- Where is located the **digital** speed sensor ON 1995 ford Aerostar 3.0 with **digital** dash?
- Is there a **digital** tuner in Samsung TV model ln-s2351w - can the TV receive off-air **digital** signal currently?

Post a question - any question - to the WikiAnswers community:

Go

EXHIBIT B

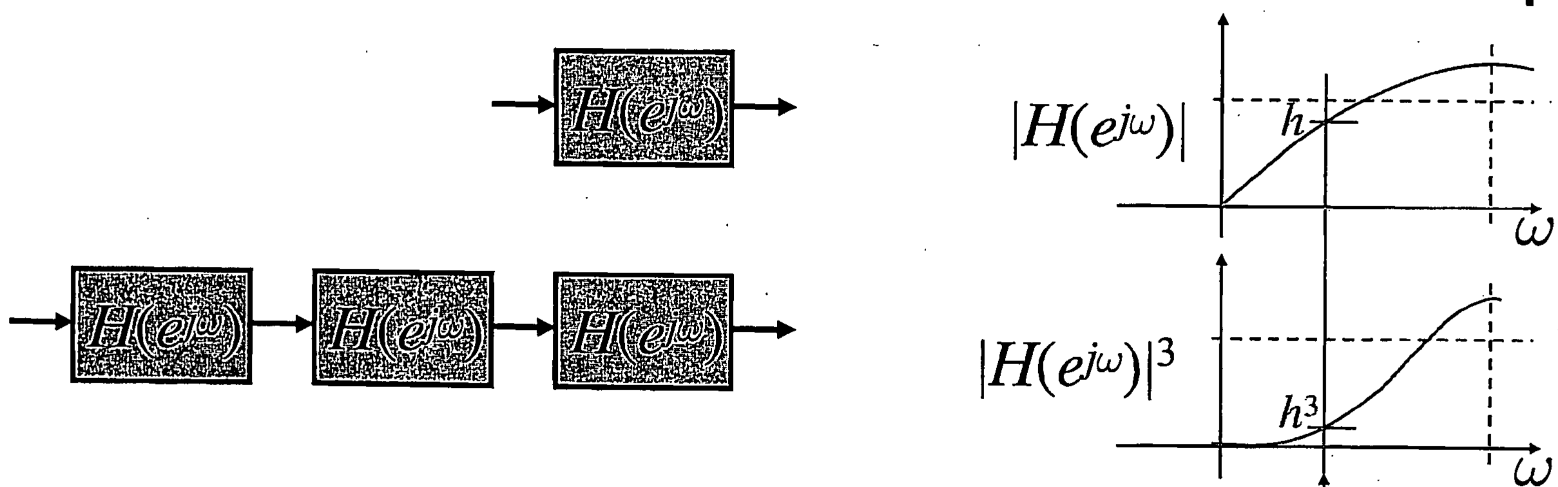
ELEN E4810: Digital Signal Processing
Topic 6: Filters - Introduction

1. Simple Filters
2. Ideal Filters
3. Linear Phase and FIR filter types

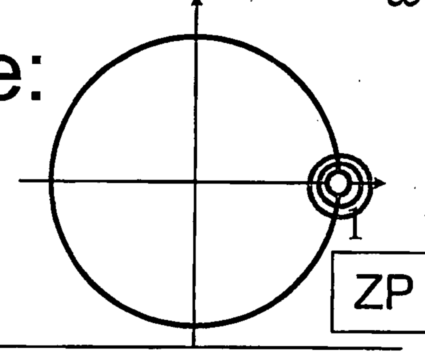
http://www.ee.columbia.edu/~dpwe/e4810/lectures/L06-filters.pdf

Cascading Filters

- Repeating a filter (cascade connection) makes its characteristics more abrupt:

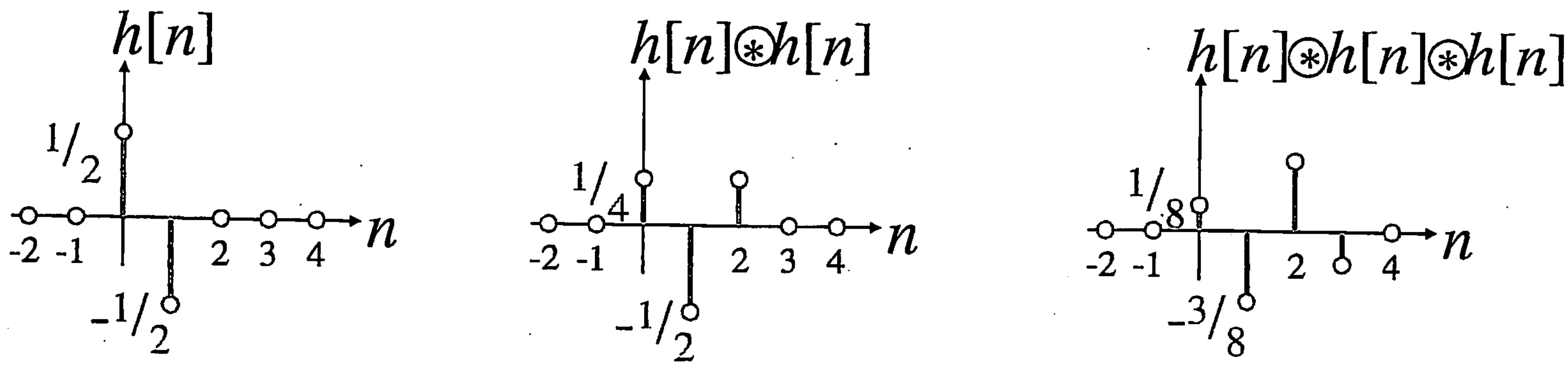


- Repeated roots in z-plane:



Cascading Filters

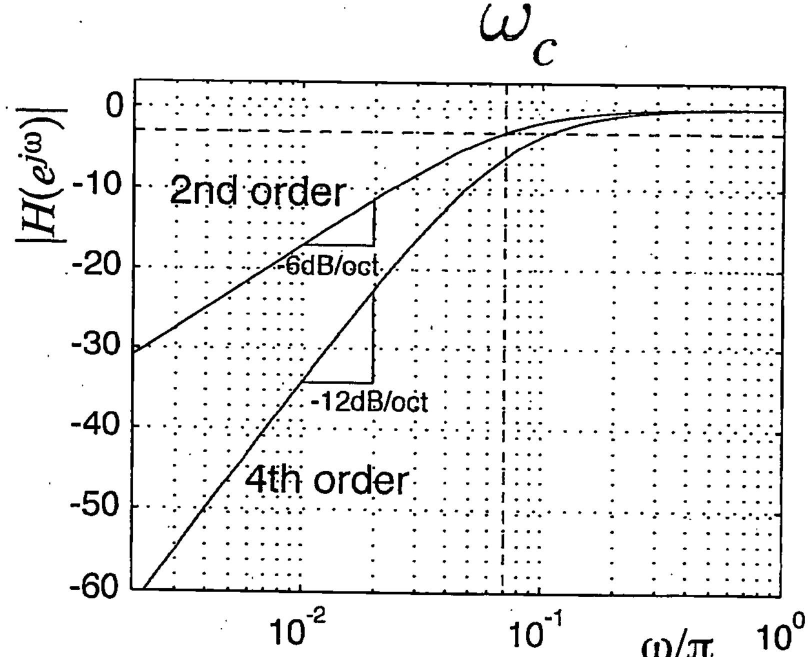
- Cascade systems are higher order e.g. longer (finite) impulse response:



- In general, cascade filters will not be optimal (...) for a given order

Cascading Filters

- Cascading filters improves rolloff slope:



- But: 3dB cutoff frequency will change (gain at $\omega_c \rightarrow 3N$ dB)